OXFORD UNIVERSITY
BIOTECH SOCIETY

Future Landscape of Engineered Proteins

Harnessing AI-Driven Design for Global Applications

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Executive Summary

Proteins are molecular machines whose function depends on their 3D structure, determined by their amino acid sequence. AI tools like AlphaFold have revolutionized protein structure prediction, enabling the design of new proteins for specific uses. This has led to a growing industry using AI to create custom proteins for applications in food, textiles, cosmetics, and agriculture, with many more sectors expected to benefit.

Proteins are small molecular machines that orchestrate all activity occurring in life, be it in humans, animals, plants or microbes. They are made up of different combinations of 20 components called amino acids. The sequence of these amino acids will determine the 3D structure and function of proteins.
This **3D structure** of a protein is crucial to its **function**; the sequence alone provides only a partial picture of a protein's functions and properties. In understanding proteins' roles in biological functions or practical and industrial applications, knowledge of its 3D structure is vital.

There are a staggering number of possible 3D structures a protein can fold into, but just **one correct structure** in its working conditions. X-ray -based laboratory methods are used to uncover these structures but are logistically prohibitive. **Artificial intelligence** has recently provided a breakthrough in predicting the 3D structure and characteristics of proteins. The work of Google's AlphaFold and Prof. David Baker in developing **AI frameworks to confidently and accurately predict the 3D structure of more than 200 million proteins** has also provided a breakthrough in the field of **protein design** and **engineering**. By modifying the amino acid sequence of a protein of interest, it is possible to change chosen characteristics in impactful ways.

As a consequence of these recent advancements, a new market and system is emerging where academics and industries interested in designing novel proteins with enhanced properties can easily utilise AI tools for their purposes. **By generating fewer but potentially effective candidate sequences via AI, candidate proteins can be manufactured and tested.** This is a far better approach than simply using higher amounts of naturally-occurring proteins for specific purposes.

Several entities are establishing themselves as early and influential players in this industry by creating **AI-based tools for specialised protein design and engineering**. Several platforms are now released and can be used by interested parties for novel protein design. **Flourish**, developed by Shiru, is a platform specialised in the design of novel plant-based proteins. **ESM3**, developed by EvolutionaryScale, **simulates the effects of natural evolution** to propose candidate protein sequences. Cradle uses g**enerative models** and **implements existing AI models** to generate candidate sequences de novo. **ZymCTRL**, developed by BaseCamp Research, furthers the understanding of properties of naturally occurring proteins, and uses naturally-occurring sequences with proven properties when suggesting novel candidate sequences.

Whilst the AI-driven revolution in protein design is in its infancy, a number of industries have already made use of engineered proteins. Several **sweet, whey and antibacterial proteins** are used in the **food industry**. **Protein fibres** and **spider silk-derived** proteins are being investigated in the **textile industry**. The **cosmetics industry** is exploring engineered **collagen and elastin** proteins. Novel **insecticidal** proteins are being produced by the **agricultural industry**, many of them having passed safety standards certifications.

As the AI-based protein design and engineering field inevitably expands and advances, we expect many other important industries to adopt this approach, such as the mining, energy, textile, chemical and construction industries.

Proteins

What is a protein?

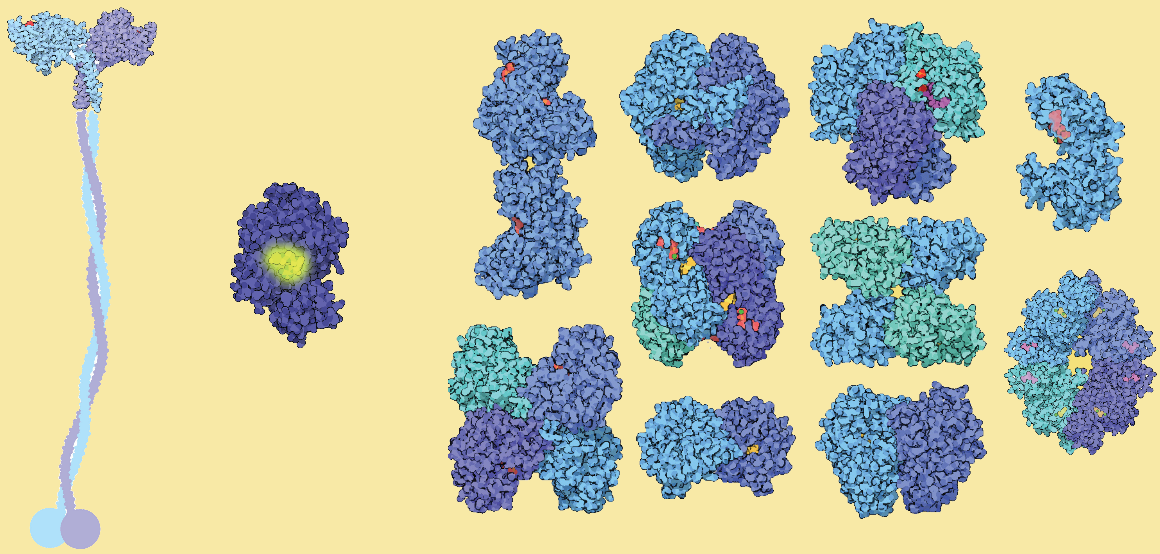
Life – at its most fundamental level – is biochemical reactions orchestrated by molecular machines commonly known as proteins. As such, proteins underly virtually every observable action of organisms: the contraction of our muscles, the light emitted by a firefly, or the fermentation process that produces a wide range of foods we enjoy everyday.

Examples of proteins and their functions[1]

- Kinesin
  Kinesin is a so-called motor protein that can convert ATP into mechanical force. As such, it underlies processes such as the transport of intracellular cargo

- Luciferase
  Luciferase is an enzyme that converts substances called Luciferin, creating light as a by-product. They are the source of light emitted by fireflies or jellyfish

- Glycolytic enzymes
  Different proteins are often assembled into a biological pathway. Glycolysis is the process by which our cells break down sugar to generate energy, and it is carried out by a total of 10 proteins



Kinesin **Luciferase** **Glycolytic enzymes**

While the term protein was first coined in the early 19th century, our understanding of these molecules only developed in the second half of the 20th century. Today, we know that proteins are chains of smaller building blocks called amino acids. The information on the sequence of amino acids is encoded in an organism's DNA. DNA contains genes, which are stretches of the DNA code that specifically code for a protein. Using a factory analogy, proteins would be the workers (or molecular machines) that carry out every task . To produce a protein, the DNA code will be read by a process known as transcription to form RNA, which in turn will translate into a chain of amino acids. These amino acids will fold up to form a protein. This fundamental biochemical transformation process from DNA to RNA to protein is known as the central dogma of biology and is universal to all forms of life from bacteria to humans.

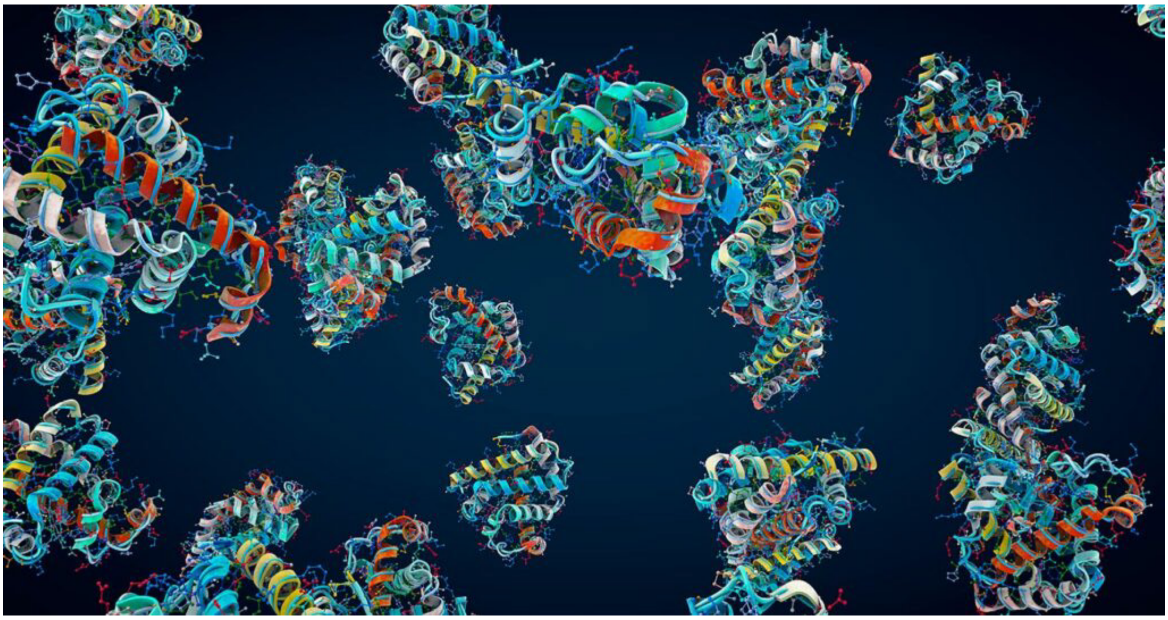


Image credit: Christoph Burgstedt/Science Photo Library/Getty Images

The Importance of Protein Shapes

Most organisms possess a repertoire of **20 amino acids** that can be assembled into a protein chain, thus providing vast combinatorial complexity. However, the two-dimensional sequence of amino acids itself provides little insight into the function of most proteins. Instead, the **three-dimensional structure** that these chains fold into after translation is the main determinant for the **properties** and **capabilities** of proteins. Importantly, different chains of amino acids, although fundamentally similar in a two-dimensional representation, can fold into drastically different three-dimensional structures depending on the biochemical properties of the chain (Fig. 1).

For example, certain stretches of amino acids may assemble into three dimensional domains that can integrate into the membranes of cells. Other amino acids may fold into scaffolding domains that allow interaction with other proteins. Thus, the **structure of a protein is of highest interest** when it comes to understanding the molecular **function** of a protein, but also to potentially **engineer** and improve those features for industrial applications.

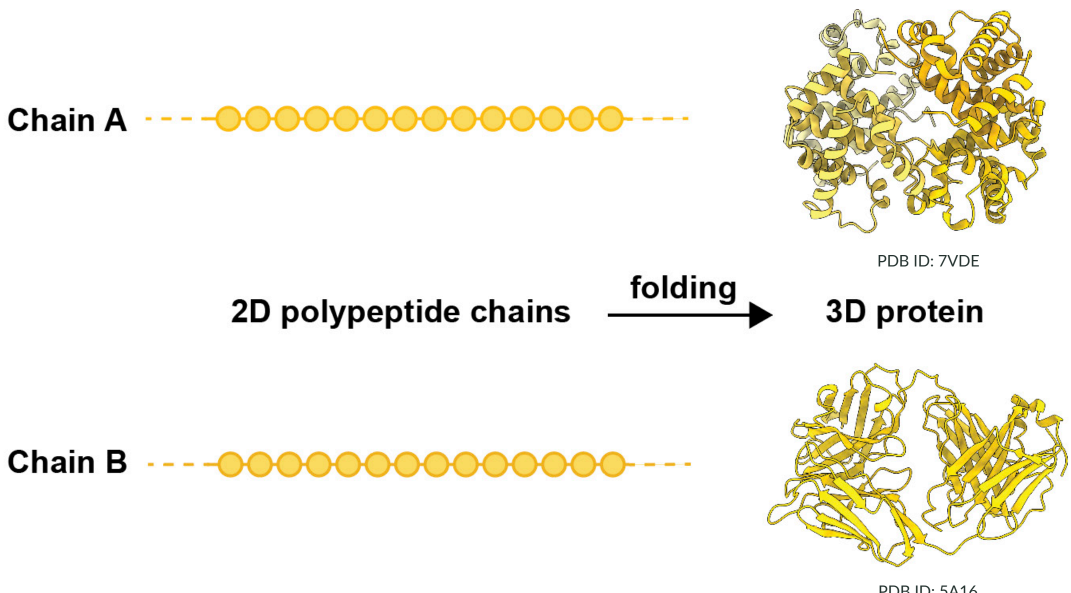


Figure 1. Three-dimensional shapes of proteins[2,3].

Protein Engineering

The Protein Folding Problem

Determining protein structures is challenging both experimentally or computationally. If a protein of 100 amino acids were to test 10 trillion different possible structures each second, or a computer were to try to simulate these, it would take 1 quintillion billion years, or 100 million billion times the estimated age of the universe, to find its correct structure[4,5].

Laboratory techniques are used to tease apart proteins' substructures, allowing scientists to determine their 3D shape. The first protein structure to be discerned via X-ray technologies was that of myoglobin, transporter of oxygen in the blood, in 1962. In 1982, only 100 or so more protein structures were known. With the advent of new technologies such as cryogenic electron microscopy, this number increased to around 10,000 in 1999, and 120,000 in 2016[6] (Fig. 2).

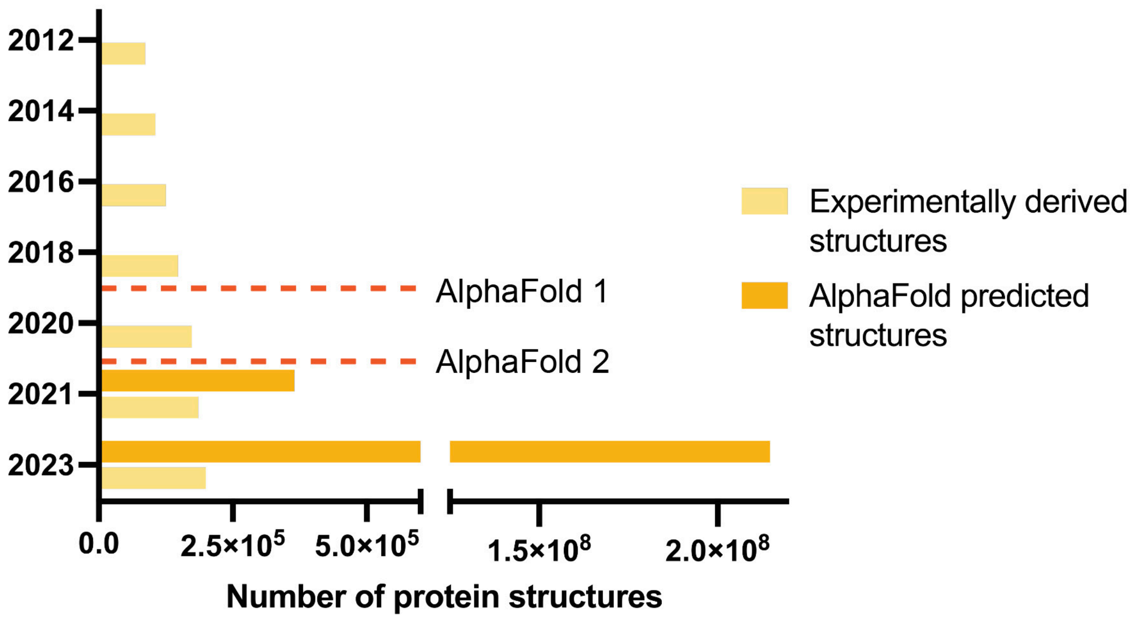


Figure 2. Growth of known protein structures over time[6]. Dashed line represents the launch of AlphaFold.

Whilst these experimental techniques allow scientists to discern the true 3D shape of proteins, their logistical constraints limit the total number of known structures.

This, however, has been revolutionised with the advent of artificial intelligence (AI). By knowing the amino acid sequence of a protein, it is now possible to computationally predict, to an exceptionally high level of precision, its folding patterns and 3D structure, thus guiding experimental research.

The speed with which AI was able to do this with millions of proteins would have been impossible to match experimentally, and these two methodologies are now considered equally relevant.

Since 2018, the groundbreaking advances in AI have allowed for the prediction of over 200 million structures, from 1 million different species, which are stored in publicly accessible databases[6] (Fig. 2).

The Artificial Intelligence Breakthrough

Thanks to the impact of this work, leaders at Google's **AlphaFold** and **Prof. David Baker**, an academic at University of Washington, jointly received the **2024 Nobel Prize in Chemistry** for developing the **AI framework** that solved the protein folding problem.

AlphaFold 1, launched in 2018, showcased the potential for this AI tool to rapidly and precisely predict the 3D structure of proteins. Whilst impressive in its speed, its bottleneck was the reliance on human-dependent and curated input data, limiting the number and size of protein structures it could predict.

AlphaFold 2, launched in 2020, was the revolutionary AI framework that was able to act independently to resolve 3D structures based on amino acid sequences. The key was building a mechanism allowing for the better understanding of the relationship between amino acids far apart in a folded protein, allowing for larger and more complex structures to be understood and predicted.

In 2024, **AlphaFold 3** was presented, with its code released for academic use. It provides considerable advances in predicting interactions between proteins, as well as interactions between proteins and other biological and non-biological small molecules.

These technologies have created breakthroughs in the world of **protein design** and **engineering**. By modifying the amino acid sequence of a protein of interest, it is possible to change chosen characteristics in impactful ways (Fig. 3).

There is immense interest in harnessing the power of AI for protein design: from increasing their utility to inventing new functions or replacing existing products with cheaper and more effective alternatives. Several early players are racing to establish themselves in this fast-growing space, bound to develop significantly as AI tools become more powerful, running costs decrease and tools and know-how become more accessible[7].

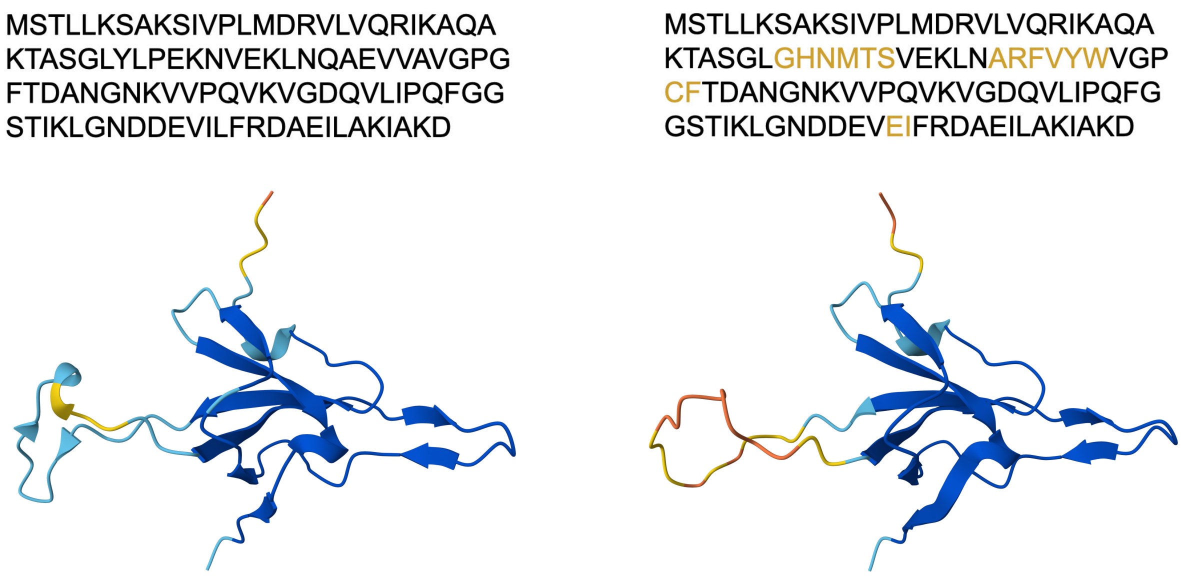


Figure 3. Changes in a protein's 3D structure as a result of altering its amino acid sequence[8].

Advances in Protein Design

The prevalent approach for the design of novel proteins is to use known amino acid sequences as a backbone, to then alter it with sequences of other proteins having sought characteristics. Ideally, this results in a protein whose original overall structure remains close to its natural one, with smaller, targeted modifications conferring it advantageous properties.

Based on the knowledge amassed from his and AlphaFold's AI models, **Prof. David Baker** and his laboratory are utilising the fruits of their labour by developing novel AI tools for protein design. They recently built AI tools that model how **proteins interact with small metallic elements**. With this, they were able to design engineered metallohydrolases, proteins that use metal molecules and water to break down structures, able to perform these difficult reactions with higher efficiencies than naturally-found ones. This class of proteins can be used for plastic degradation or breaking down man-made environmental pollutants [9-12].

Shiru, which recently raised $16m in series B funding[13], uses AI for the discovery of novel protein-based ingredients. Its platform, called **Flourish**, uses the known structures and amino acid sequences of naturally occurring proteins in plants. This allows them to obtain deep knowledge on their properties, which is then used to design new candidate proteins with chosen characteristics[14]. Through their AI-driven protein design platform, they were able to **design and produce a novel plant-based protein ingredient that tastes and behaves like animal fat, but without the environmental consequences**[15]. This has secured them a partnership with a large-scale commercial food ingredient manufacturer.

EvolutionaryScale, which recently raised $142m from prominent figures in a seed round[16], developed **ESM3**, an AI model used for the design of novel proteins, utilising data from ~2.8 billion natural proteins. In nature, proteins undergo **evolution** for hundreds of millions of years, with their amino acid sequence varying significantly as a result. ESM3 is leveraging this principle to design novel proteins based on the amino acid sequences of current natural proteins by **simulating the effects of evolution**, without the constraints the natural world would have on it[17].

They showcased ESM3's ability to mimic evolution by generating a fluorescent protein whose amino acid sequence is largely dissimilar to known sequences able to generate fluorescence. Fluorescent proteins are vastly used in biotechnology, with only a handful known and that have evolved naturally throughout millions of years. ESM3 was fed a few amino acid sequences of a known green fluorescent protein (GFP), and through a 2-step iterative process, testing only 192 candidate sequences, was able to generate the sequence that led to a novel GFP protein, called **esmGFP**, which had fluorescence levels comparable to natural GFP[18]. This novel protein, generated through ESM3's strategy of simulated evolution, shared less than 58% of natural GFP's amino acid sequence. **This amount of variation is estimated to take 500 million years to occur naturally**, a process EvolutionaryScale was able to perform in a process that could take a few months by multimodally reasoning over sequence, structure and function.

Cradle, which recently raised $73m in Series B funding to expand its operations[19], developed and continues to advance its AI platform specialising in the design of novel proteins used in the therapeutic, diagnostics, agriculture, chemicals and food markets[20]. They seek to establish themselves by utilising **generative models** to generate amino acids sequence de novo, i.e. without using a known sequence as a backbone. They also specialise in developing implementation protocols with other AI models and optimize experimental procedures to test candidate protein sequences[20].

Recently, Cradle used its AI platform to design a protein that binds to a **therapeutic cancer target** with higher efficiency than the current ones from Merck[21]. They were able to come up with a handful of candidate amino acid sequences by setting up parameters in less than an hour on their platform, and letting it run overnight. The process did not require manual intervention, and the candidate sequences were considerably different to current standards.

Advances in Protein Discovery

The discovery of still unknown natural proteins and understanding of their properties is beneficial to further train AI models, which will be able to better predict the impacts of changing amino acids and generate more effective candidate sequences.

Image credit: Basecamp Research

Basecamp Research, which recently raised $60m in Series B funding[22], aims to harness AI tools to bolster their **protein discovery** efforts. They run the largest biodiscovery programme ever, with the aim of sampling microbes and natural entities across the globe, including habitats in harsh environmental conditions, to create an atlas of natural microbial proteins[23]. They do so ethically, with local consent, following international sampling regulations.

Through the building and curation of this database (**BaseGraph**), they utilise their AI tool **ZymCTRL** to **understand the properties** of their discovered natural proteins. This allows the tool to provide **novel candidate proteins** with chosen characteristics based on the **amino acid sequence of naturally-occurring proteins** having these characteristics. By combining protein discovery with AI development, they allow researchers and customers to use ZymCTRL for the design of tailored proteins, utilising **knowledge acquired from natural, existing and time-tested proteins**. They sought to use ZymCTRL to design a **novel lactate dehydrogenase (LDH)** with enhanced capabilities. In doing so, they were able to design a novel version of the protein, sharing less than 40% of the amino acid sequence to the original. They were able to demonstrate that it could **perform as well as the natural one in a larger temperature range, in harsher acidic conditions, and could maintain its activity after being frozen and thawed**[24,25]. This could have important implications in food manufacturing processes, where LDH is often used to regulate the amount of by-products from fermentation.

An increasing number of **AI tools for protein design**, including ones for specialized purposes and applications, are being developed and refined. Because **using designed proteins with befitting characteristics to fill a need or purpose is a far more effective strategy than simply scaling up the usage of naturally occurring ones**, the ability to easily design novel candidate proteins, with selected characteristics addressing specific needs, with just a computer and an Internet connection will revolutionise the use of engineered proteins.

Real World Applications

Protein engineering has been exploited for decades to produce industrially applicable enzymes and proteins, and it has yielded significant benefits across various fields. One of the earliest and most successful applications of engineered proteins has been in medical sciences focusing on therapeutics development. With the recent rise in machine learning and AI technology, protein engineering is becoming increasingly adopted by researchers to create innovative solutions to address global challenges. The ability to design and manipulate proteins with unprecedented precision unlocks the true potential of these powerful molecular machines. These 'designer' proteins, with their enhanced characteristics and functionalities, often represent a more efficient alternative than their naturally occurring predecessors. As a result, companies across a wide range of industries are actively developing novel proteins as sustainable and effective replacement to many traditional approaches.

The Coherent Market Insights predicted a growth from USD 4.21 billion in 2025 to USD 12.26 billion by 2032 in the protein engineering market, with a compound annual growth rate (CAGR) of 16.5%[26] (Fig.4). The trajectory includes the expansion of engineered protein demands across multiple sectors including food, healthcare, and industrial applications.

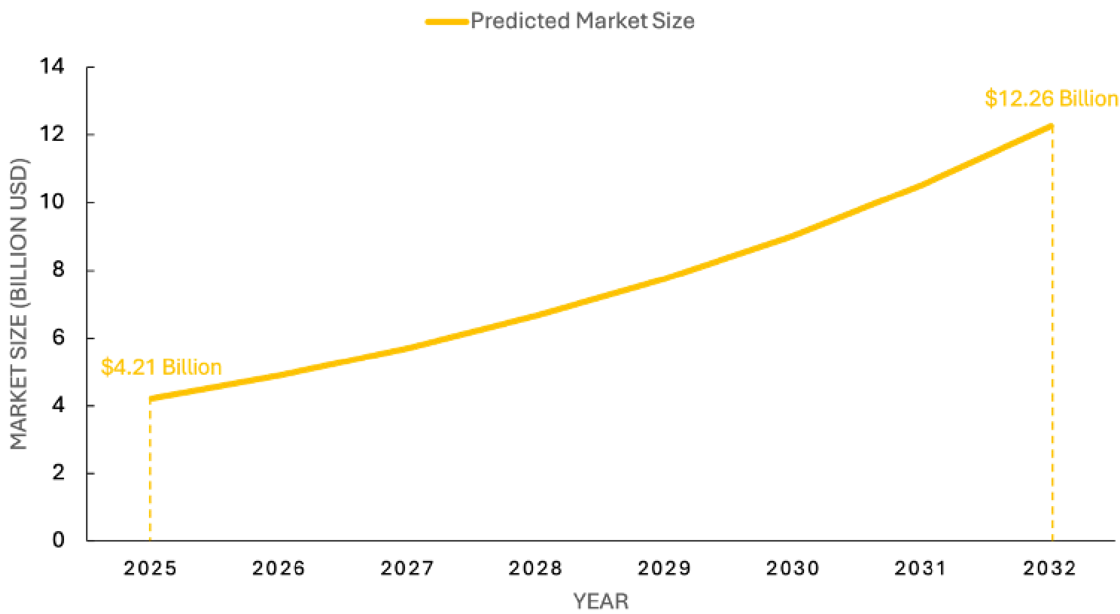


Figure 4. Projected global market size for engineered proteins (2025 - 2032)[26].

Industries Disrupted by Protein Design

Food Industry

Whilst proteins are not new in the food industry, advances in protein engineering have enabled the creation of novel proteins that exhibit superior flavour profiles and nutritional contents to traditional ingredients.

Sugar overconsumption dramatically increases the risks of many health conditions, including obesity, diabetes and cardiovascular diseases. The overcultivation of sugar cane and the downstream processing of sugar also pose severe threats to the environment. To address these challenges, the Israel-based company **Amai Proteins** developed a novel designer sweet protein **Sweelin®** that is over 3,000 times sweeter than sugar. Sweelin® was inspired by a natural sweet protein found in serendipity berries, and it was engineered to resemble those proteins that exist in harsh environments such as hot springs, the Dead Sea and acidic swamps. Using AI computational protein design, Amai created a tasty hyper-sweet protein with enhanced characteristics that are fit for the mass food market. Sweelin® has currently received self-affirmed Generally Regarded As Safe (GRAS) and GRAS approval from Flavour Extract Manufacturing Association (FEMA). Amai has also completed a clinical trial on Sweelin® which confirmed that a high dose of the protein does not impact blood glucose or insulin levels in humans. The company aims to apply its Pro3 platform technology to create other designer protein products for applications in the world of meat, plant and milk proteins.

The ever-growing global population and the shift in dietary patterns have led to an increasing demand for animal proteins, including diary, meat and eggs, worldwide. However, traditional food systems, like dairy farming, are a significant contributor to environmental degradation. **Verley**, a French company founded in 2022, is dedicated to bringing sustainable solutions to the dairy industry. Using precision fermentation, Verley produces engineered milk proteins (β-lactoglobulin) **FermWhey™** that contains 11% more leucine than native whey protein isolate. It has also developed two functionalization strategies to engineer whey proteins with enhanced features like heat and acid resistance as well as gelling properties. With these functional advantages, Verley provides an alternative sustainable dairy protein source that can be formulated into many food and beverage products. Its portfolio of protein powders has received self-affirmed GRAS and are expecting full commercial availability in 2026.

Textile Industry

Driven by the rise of fast fashion, the textile industry is causing significant environmental issues worldwide. The generation of fibres, whether it be from chemicals or natural sources, leads to high emission of greenhouse gases and often depletes non-renewable resources. To tackle this problem, several biotech companies are developing synthetic protein fibres with superior textile performances as sustainable alternatives.

Spiber, a company based in Japan, has been creating synthetic protein fibres since 2007. Its **Brewed Protein™** fibres consist of proteins that are specifically designed for textile applications and can be processed into a variety of forms, ranging from delicate filaments with a silky sheen to spun yarns that have cashmere-like softness or the loftiness of wool. These protein polymers can also be broken down and re-used as feedstocks to produce new fibre materials. In 2019, Spiber launched its Brewed Protein™ fibres in collaboration with the sportswear brand Goldwin. Since then, it has been featured in various clothing products by brands like The North Face. The company is currently working with collaborators to develop new protein fibre materials with fur and leather-like textures. Unlike Spiber that engineesr proteins to create polymers with different properties, the UK-based company **Solena Materials** produces synthetic fibres from new-to-world designer proteins. With the help of AI and deep learning models, Solena aims to design novel protein sequences that can form high performance fibres and be upscaled for industrial production. The company has recently received grant funding from Innovate UK to continue its research in sustainable fibres in partnership with the National Physical Laboratory.

Agriculture Industry

Traditional chemical-based pest controls are known to drive biodiversity loss and impact human health. The overuse of broad-spectrum chemicals has also led to a widespread problem of insect resistance, potentially putting crop yields in danger. Therefore, there is an urgent need to develop a new generation of environmentally friendly, safe and effective pesticides for the agriculture industry.

The US biotech company **Vestaron Crop Protection** was founded in 2005 with the mission to create novel, effective and sustainable crop protection solutions for modern agriculture. Inspired by proteins found in animal venoms, Vestaron modifies and manufactures insecticidal peptides (small proteins) that exert neurotoxic effects on target pest insects. In 2020, its first peptide-based insecticide **SPEAR®** targeting a range of Lepidopteran pests was commercialised. Vestaron now has two active peptide ingredients in its pipeline and the company is working with global agriculture leader ADM to deliver innovative pest management solutions to farmers worldwide. Similar to Vestaron, the UK-based **SOLASTA Bio** has also been developing bio-safe pest controls from insect neuropeptides. It has created a platform technology to engineer peptides with targeted insect specificity and unique mode of action. Its non-toxic precision crop protection solutions were also shown to be at least as effective as traditional chemical insecticides in field trials. The company has now secured a biochemical-like classification from the US Environmental Protection Agency (EPA) for its lead candidates and is planning for a market entry in 2027. A more recent market player that has just emerged this year is **Quercus Biosolutions**. Different from Vestaron and SOLASTA Bio that engineer naturally occurring peptides, Quercus is determined to design novel peptides or micropeptides as crop protection products. It partners with the drug discovery company Ordaos Bio to apply the latter's generative AI platform to develop designer proteins from scratch. For now, the company has generated proof-of-concept data proving that designed 'mini-proteins' can work in live plants.

Cosmetics Industry

Proteins are one of the most important active ingredients in the cosmetics industry and their use can be dated back centuries. Currently, the majority of these peptide ingredients still rely on animal-derived proteins or chemical synthesis which raises concerns over their links to negative environmental and ethical impacts.

Hoping to deliver more sustainable protein solutions, the US-based **Geltor** developed a portfolio of active polypeptides using its biodesigner AI™ platform. Its flagship products **HumaColl™21** and **Elastapure®** were specifically designed to mimic human type XXI collagen and elastin proteins. Geltor is also inspired by nature – its **Collume®** collagen polypeptide was created based on marine animals whilst its **Caviance®** polypeptide was designed with a unique sequence that resembles sturgeon type II collagen. In addition to beauty products, the company is looking to apply its technology platform to create novel protein ingredients for food and medical applications. Sharing the same vision, the UK company **Xias Bio** was founded in 2020 to create sustainable protein solutions for the cosmetics industry. With its own protein engineering platform **LiteProtein™**, Xias designed families of chimeric proteins that integrate active motifs found in a range of naturally occurring proteins. For example, its **CollaLite™** takes in collagen peptides sourced from various species for enhanced performance; its **ElastiLite™** combines the mechanical strength of silk with elastin and its **SeaLite™** utilises natural UV-absorbing peptides from Sea Cucumber to boost SPF. The company has already licensed some of its proteins to major leaders in the beauty industry. Ultimately, Xias aims to replace all single-function animal proteins with sustainable high-performance multifunctional alternatives throughout industries, ranging from pharmaceuticals to agriculture. **Bolt Threads**, based in the US, is another biotech company that is interested in bringing sustainable materials to the cosmetics world. It designed a silk polypeptide that mimics the structure of natural spider silk and displays film-forming properties, allowing it to function as an alternative to silicone elastomers. In 2018, Bolt launched its **b-silk™** polypeptide which has since been featured in skincare and haircare products of several cosmetic brands.

Designer proteins have already gained much commercial interest in various sectors, including the pharmaceutical, food, textile, agriculture, and cosmetics industries. The recent rise in protein design tools further drives and empowers innovation which opens doors to potential protein-based applications in many other areas, such as:

- Mining industry

Lanmodulin for **metal extraction** – a group in the US immobilised the lanthanide-binding protein onto agarose microbeads for the separation of rare earth elements from complex aqueous feedstocks[27]

- Energy industry

Methane monooxygenases for **methanol production** – a group in South Korea reassembled minimal components of the soluble methane monooxygenase on apoferritin scaffold for rapid and high-yield methanol production in *E. coli*[28]

- Textile industry

Chromoproteins as **textile dye** – a group in Australia engineered chromogenic fusion proteins, consisting of a chromoprotein and a carbohydrate-binding module (binds cellulose), as colouring agents for cotton[29]

- Chemical industry

Peroxygenases as **biocatalyst** – a group in Germany engineered unspecific peroxygenases to improve their heterologous expression for potential use as biocatalyst in industrial oxygenation reactions[30]

- Construction industry

Urea as **chemical reaction modifier** – urea (and other enzymes) are used to improve biocementation processes. Enzymatic by-products provide required molecules for binding materials together or repair damaged structures[31]

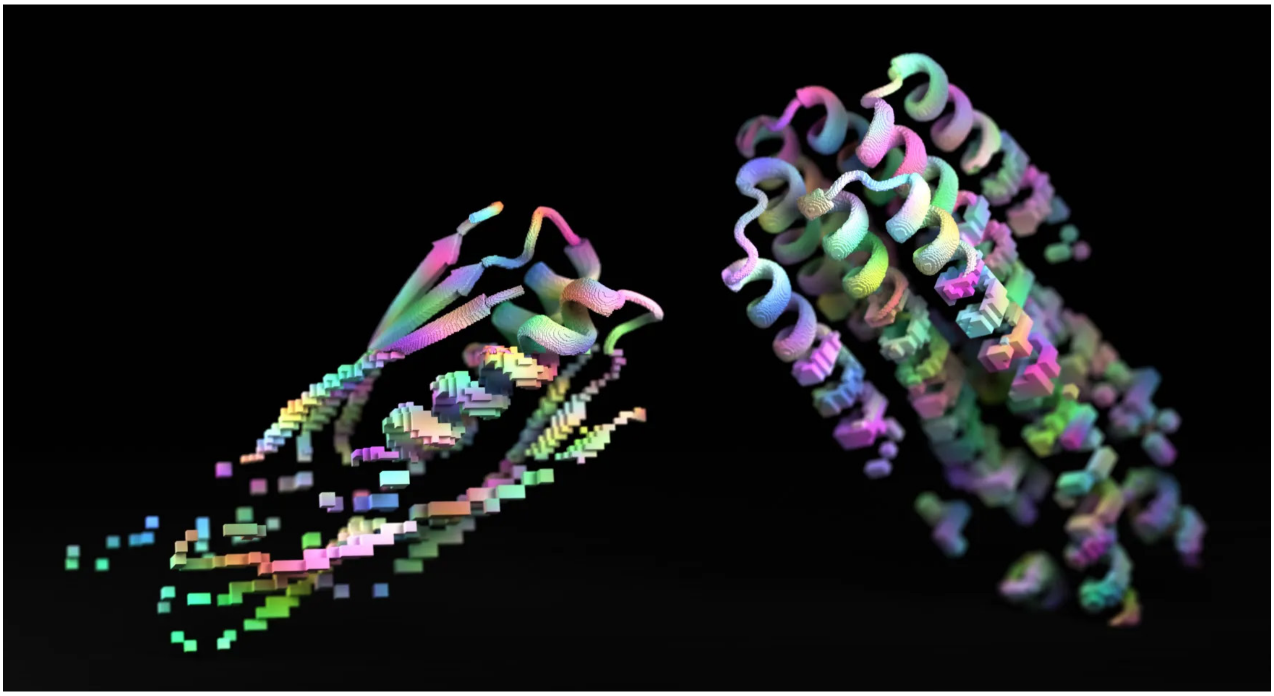


Image credit: University of Washington

Looking Ahead

The field of engineered proteins is entering a **transformative phase**. Advances in AI tools have accelerated protein design, and applications are now emerging across food, cosmetics, agriculture, materials and energy, from every-day aspects in our lives, to scaled production in industries. These **engineered proteins** are offering **cleaner, smarter alternatives** to traditional products, from everyday consumer goods to industrial scale processes.

Despite this momentum, several challenges remain. First, scalable manufacturing remains the key bottleneck, especially for novel sequences that push the boundaries of traditional expression systems. Meanwhile, functional outcomes are still difficult to predict from structure alone, making **rapid and reliable functional testing essential**. Additionally, regulatory frameworks must be aligned to accommodate new protein products, particularly in food and cosmetics, where consumer acceptance is critical. Discovering and designing proteins with superior functionality to the incumbents they are replacing will be key to delivering them at competitive cost in-use, driving market adoption.

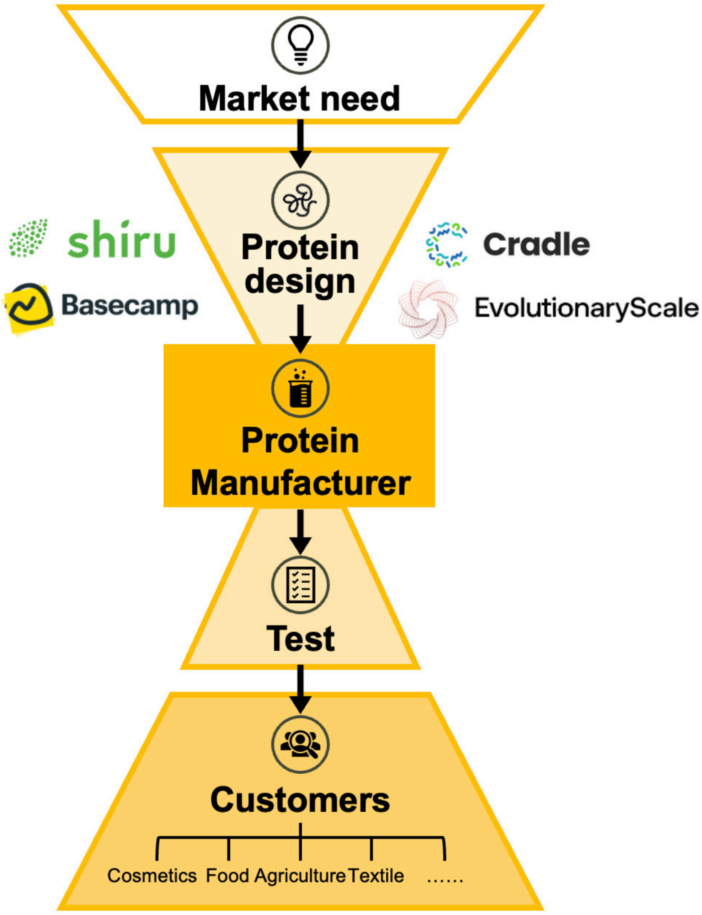


Figure 5. The workflow to deliver engineered proteins to market.

As we stand at the intersection of biology and computation, proteins are no longer just products of nature — they are becoming **tools of design**. With **sustained investments**, **technical innovation** and **cross-sector collaboration**, engineered proteins could transform how we feed, clothe, treat, and power the world. The protein revolution is still in its early stages, but its impact is already starting to take shape across key industries.

Contributors

Project Leads

Angela is a DPhil student at the department of Biochemistry. She studies the mechanism of action and the uptake pathways of protein toxins in Gram-negative bacteria, aiming to design and engineer novel antibiotics against multidrug-resistant bacteria.

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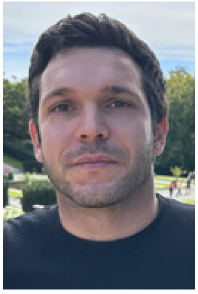

Ramy is a DPhil student at the Weatherall Institute of Molecular Medicine. He utilises single-cell multi-omic approaches to parse the hetergenous landscape of solid and liquid tumours to investigate differences in treatment responses and disease progression.

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